실리콘 RF MEMS 스위치 기반의 RH/LH 모드 스위칭이 가능한 CRLH 전송선 제작 및 측정

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Fabrication and measurement of RH/LH mode-switchable CRLH transmission line based on silicon RF MEMS switches

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Abstract - This study proposes a composite right/left-handed transmission line (CRLH-TL) that permits switching between the right-handed (RH) and left-handed (LH) modes using single crystalline silicon (SCS) RF MEMS switches. It is possible to change modes from the RH to LH mode, or vice versa, by controlling the admittance of capacitors and the impedance of inductors using switch operations. The proposed switchable CRLH-TL consists of SCS RF MEMS switches, metal-insulator-metal (MIM) capacitors and shunt inductors. At 8 GHz, the fabricated device shows a phase response of 87° with an insertion loss of 2.7 dB in the LH mode, and a phase response of -77° with an insertion loss of 0.56 dB in the RH mode.

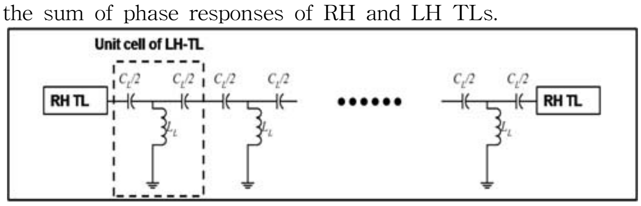
1. Introduction

Since the CRLH-TL was first introduced, various researches have been conducted to make use of it in microwave applications such as couplers, antennas, and filters [1-3]. By replacing conventional TLs with CRLH-TLs, it is possible to develop RF applications that have arbitrary dual-band operation, or to reduce the size of the devices dramatically. Meanwhile, studies to improve performances of the CRLH-TL itself also have been presented, especially to enlarge its field of applications by adding tunability. Methods to demonstrate a tunable CRLH-TL using ferroelectric varactors or pin-diodes have been studied, but they have some weaknesses; narrow tuning range, poor yields, and low operating frequency. MEMS technology is expected to become an alternative solution because of its better performances such as low loss, small size, and high operating frequency. However, experimental results have yet been reported to date [4], because it is difficult to integrate elements of a CRLH-TL with switches, and to operate plural tunable devices stably.

In this study, we proposed a switchable CRLH-TL using RF MEMS switches. Switches are based on silicon MEMS technology which has structural stability and deformation-free characteristics. The proposed device changes the impedance and admittance of the inductors and capacitors, respectively, according to the switch configuration, thereby enabling switching between the RH and LH modes.

2. Design

The equivalent circuit of a conventional CRLH-TL is described in Fig. 1. It presents RH and LH TLs that are connected in series. Total phase response of the CRLH-TL is the sum of phase responses of RH and LH TLs.



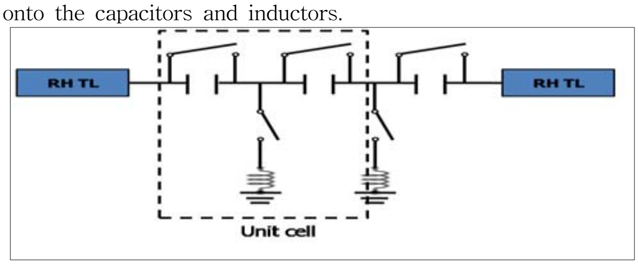
<Fig. 1> Equivalent circuit of conventional CRLH-TL

If a phase response in regard of the unit cell of LH TL is less than $\pi/2$, it is derived as

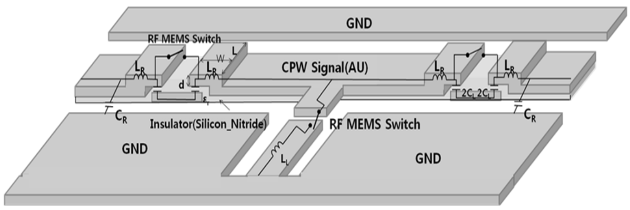
$$\Phi_L = \frac{1}{w}\frac{1}{\sqrt{LC}} \tag{1}$$

where w is the frequency, L is the inductance and C is the capacitance. Thus the phase response is inversely proportional to frequency, and its value is always positive. On the contrary, the phase response of a RH TL is proportional to frequency and always negative. Therefore, the phase response of CRLH-TL shows LH characteristics at low frequencies and RH characteristics at high frequencies. If it is possible to switch between the RH and LH states, a switchable CRLH-TL that has both features of phase lag and phase advance can be realized.

Based on the CRLH-TL with two unit cells, equivalent circuit of the designed switchable CRLH-TL was shown in Fig. 2. (a). Switches are connected with capacitors in parallel and with inductors in series. Impedance of the inductor and admittance of the capacitor are changed by switch operations. To integrate silicon MEMS switches with the designed CRLH-TL, a structure as shown in Fig 2.(b) is proposed. The structure facilitates efficient integration by putting switches onto the capacitors and inductors.



(a)



(b)

<Fig. 2> (a) Equivalent circuit of the proposed switchable CRLH-TL and (b) schematic of the proposed switchable CRHL-TL's unit cell

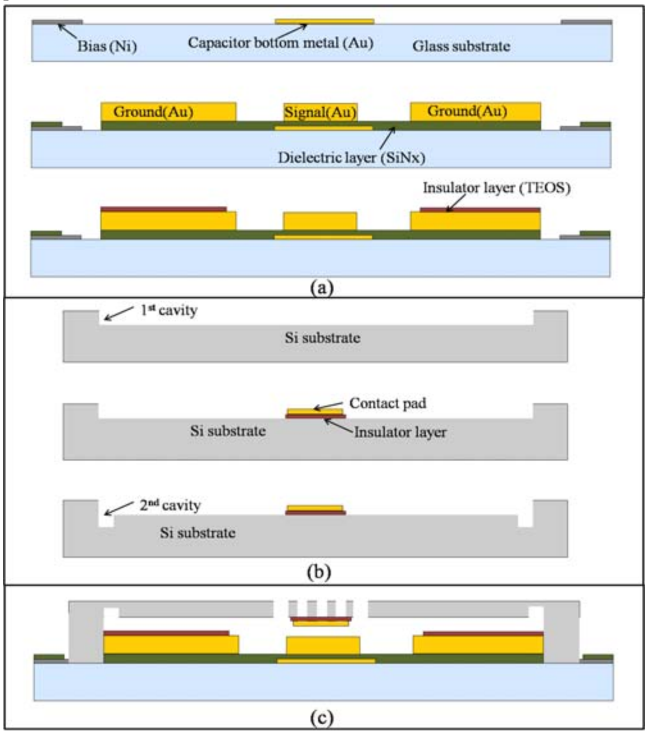
3. Fabrication

To fabricate the designed switchable CRLH-TL, a CPW, inductors, and capacitors were formed on a glass substrate. Silicon switches were transferred to the glass substrate from the silicon substrate through pattern transfer using SiOG process. Fig. 3 shows the fabrication process, focused on the capacitor parts.

The fabrication process for the glass substrate starts with forming of the nickel bias lines and the gold bottom electrodes of capacitors on the glass substrate. Then, a 0.65 ㎛-thick silicon dioxide layer was patterned as a dielectric layer. Gold CPW TLs with a thickness of 3 um were patterned on the dielectric layer. At next, a silicon dioxide insulating layer was formed on the ground of CPW to avoid short with silicon switches.

Switch structures were fabricated on a silicon substrate. Firstly, in order to define the initial gap between the electrodes of silicon switches, the first cavity was formed. Inside of it, an insulating layer and gold pad are patterned to make the contact part. Finally, the second cavity was made to adjust the thickness of switch springs.

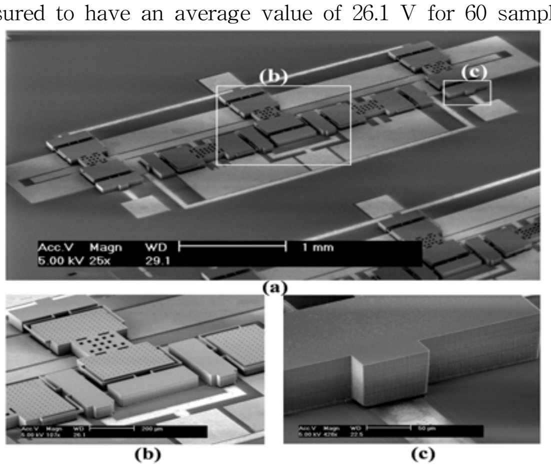
The completed glass and silicon substrates were bonded together using anodic bonding process, followed by thinning through CMP process in order to control the thickness of switches. Finally, switches were released using dry etching process.



<Fig. 3> Fabrication process of (a) glass substrate, (b) silicon substrate and (c) bonding and release

4. Measurement results

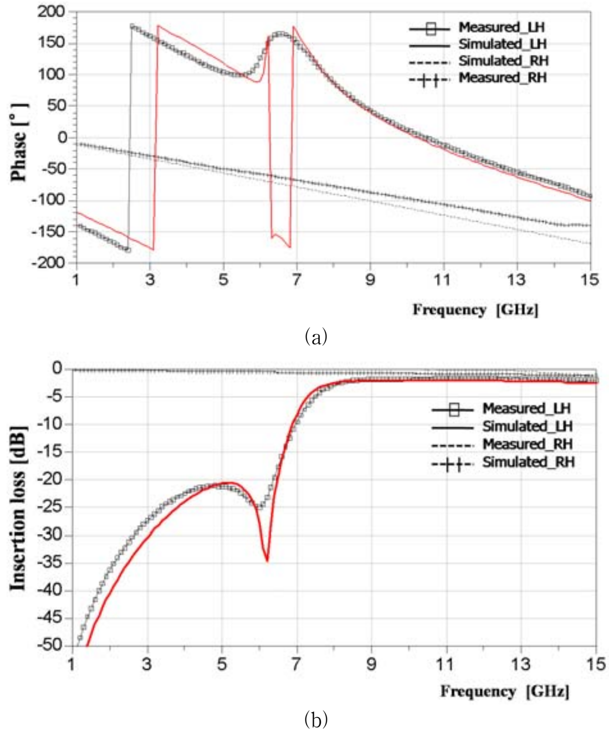
Fig. 4 shows SEM images of the fabricated switchable CRLH-TL. The image verifies the switch structure is well defined, and the bias and signal lines are formed without disconnection. Pull-in voltages of the fabricated switches were measured to have an average value of 26.1 V for 60 samples.



<Fig. 4> SEM images of (a) the fabricated switchable CRLH-TL, (b) SCS RF MEMS switch, and (c) bias parts

Fig. 5 shows the measured RF characteristics of the switchable CRLH-TL. In the LH mode, the phase response shows phase advance below 10 GHz and phase lag over 10 GHz. In the RH mode, the phase response was measured to have always negative values as conventional TLs.

At 8 GHz, which is specified as a target frequency, the phase was shifted by an amount of 164°, from 87° to -77° by switch operation. Insertion losses were 2.7 dB and 0.56 dB at the LH and RH modes, respectively. In the LH mode, the return loss was measured over 15 dB from 8 GHz to 15 GHz. In the RH mode, the return loss was measured over 30 dB from 1 GHz to 15 GHz.



<Fig. 5> Measured and simulated (a) phase responses and (b) insertion losses of the fabricated switchable CRLH-TL

5. Conclusion

In this study, a switchable CRLH TL using SCS RF MEMS switches was demonstrated. The proposed device was designed and fabricated based on conventional SiOG process. RF MEMS switches and passive elements are integrated vertically. The fabricated switchable CRLH-TL was measured to have a phase response of 87° and an insertion loss of 2.7 dB in the LH mode, and a phase response of -77° and an insertion loss of 0.56 dB in the RH mode at 8 GHz. A mode switching capability between the LH and RH modes using RF MEMS switches was successfully demonstrated.

[Reference]

[1] I. Lin, M. Devincentis, C. Caloz, et al., "Arbitrary dual-band components using composite right/left-handed TLs," *IEEE Trans. Microwave Theory Tech.*, vol. 52, pp. 1142-1149, April. 2004.

[2] D. kuylenstierna, A. Vorobiev, P. linner, et al., "Composite right/left handed transmisstion line phase shifter using ferroelectric varactors," *IEEE Microwave and Wireless Compon Lett.*, Vol 16, no. 4, pp. 167-169, April 2006.

[3] Y. Wang, Y. Zhang, L. He, et al., "Tunable asymmetric composite right-/left-handed TL directional coupler controlled by applied voltage", *IEEE Asia-Pacific Microwave Conference (AMPC) 2005*, vol. 1, Dec. 4-7 2005.

[4] S. Mao, M. Wu, Y. Chueh, et al, "Modeling of symmetric composite right/left-handed coplanar wave guides with applications to compact bandpass filters," IEEE Trans. Microwave Theory and Tech. vol 53, no 11, pp 3460-3466, Nov. 2005.